Appendix B

Electromagnetic Borehole Flow Meter Testing

QEC

QEC - T - 148

Electromagnetic Borehole Flowmeter At a Permeable Barrier Site In Vancouver, Washington

by

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Introduction

Quantum Engineering Corporation (QEC) conducted a flowmeter test in Vancouver, WA for the Pacific Northwest National Laboratory (PNNL). The tests were performed under subcontract to Battelle Institute, the prime contractor for the U.S. Department of Energy. These tests were performed by QEC for Batelle Institute on 21-23 August 2002 in support of a permeable barrier to remediate a groundwater plume. The flowmeter data served as the basis for determining the vertical distribution of horizontal hydraulic conductivity along the barrier. These data, along with other geologic data from the site, will be used to improve the effectiveness of the remediation process and possibly reduce the total cost of the barrier installation.

Hubert Pearson of QEC performed the flowmeter test described herein using the Electromagnetic Borehole Flowmeter (EBF). Mr. Pearson has previously performed similar flowmeter tests at a permeable barrier site at PNNL in March and April of 2002 using the same instrument system and a similar test procedure. The instrument system, the method used to collect data, and an explanation of how the data are used to compute a vertical distribution of hydraulic conductivity are described in Waldrop and Pearson (2002). Additional details of the field procedure and data analysis can be found in Molz, et al (1994).

Results of this analysis are presented in a similar format for ease in interpreting results from the two previous tests at PNNL. As before, Mr. Pearson was assisted in the field by staff of Battelle Institute. Vince Vermeul of Battelle Institute provided guidance in planning and conducting the test program and served as the primary contact.

Test Results

The flowmeter test was performed with the QEC EBF system using the half-inch i.d. probe. This probe was selected because it provides better accuracy in the low flow range, and limited capacity was available to store the purge water from pumping. The EBF system produced a linear signal throughout the range of flows tested. Upward flows were designated as positive as the sign convention used throughout all testing. Depths reported are referenced to ground surface.

QEC furnished the EBF system, a small pump, and a water level measuring device. PNNL provided a GrundFos RediFlo2 downhole pump and controller, and arranged for collection and disposal of all purge water. Electric power for the EBF system and the pump was available at the site.

Ten wells were successfully tested. Nine of the 10 wells had been completed with a nominal 2-inch diameter screen. Six of these nine wells contained wire-wrapped stainless steel screen, and three contained slotted PVC screen. The downhole probe provided a snug fit in the PVC slotted screens, but the vertical ribs of the wire-wrapped screen precluded sealing the region between the outside of the EBF probe and the screen to prevent all bypass flow around the recording interior of the flowmeter. Nevertheless, a successful flowmeter test was achieved by blocking a consistent percentage of vertical flow. The relative change in flow rate between vertical stations is what is required to determine the profile of hydraulic conductivity of a well.

The tenth well was designed as an injection well. It was six inches in diameter and completed with a wire-wrapped screen. A rubber collar sized slightly larger than the screen diameter was used to block as much of the flow as possible between the outside of the EBF probe and the screen. An inflatable packer can also be used to block vertical flow around the probe. However, an inflatable packer is more time consuming and requires care to assure that the packer is inflated to the same diameter for each depth.

Ambient tests were not performed on any of the ten wells. It is assumed negligible for the analysis. The drawdown in all of these wells was also found to be negligible at the low pump rates used.

The parameters for the wells tested are presented in Table 1. All depths are recorded from the top of the casing that was essentially ground level. Staff of PNNL using a calibrated bucket and a stopwatch measured the pump rates.

Table 1: Parameters of the Wells Tested

Well No.	**Diameter**	**Type**	**Screen Length**	**Depth to Water**	**Pump Rate**
	(In.)		**(Ft.)**	**(Ft.)**	**(GPM)**
Injection 1	6	Wire-Wrap	20 to 35	?	4.0
MW 1	2	Wire-Wrap	22 to 35	20.70	0.74
MW 3	2	Wire-Wrap	22 to 37	20.40	0.72
MW 4	2	Wire-Wrap	20 to 35	20.32	0.73
MW 5	2	Slotted PVC	20 to 35	20.40	0.65
MW 6	2	Slotted PVC	20 to 35	20.50	0.67
MW 10	2	Wire-Wrap	20 to 35	20.30	0.63
MW 20	2	Wire-Wrap	22 to 27	20.35	0.67
MW 21	2	Wire-Wrap	30 to 35	20.42	0.67
MW 22	2	Slotted PVC	35 to 40	20.35	0.67

A downhole pump was used to test Injection Well 1 because a higher pump flow rate was selected for the six-inch diameter wire wrapped screen. Because of pump interference near the water surface, it was only possible to position the flowmeter probe to a depth of 23 feet. Therefore, flow rates in the top three feet of the screen were not tested.

A peristaltic pump was used to test all nine of the two-inch diameter monitor wells. This was accomplished by placing the intake hose for the pump as near the water surface as possible. This permitted the test engineer to raise the flowmeter probe near the water surface to test as much of the screened interval as possible. For those wells were the top of the screen was positioned at depths of 22 feet or deeper, it was possible to record flows over the entire screen length. For the five wells where the screen extended above the water surface, adequate data were recorded to provide a good profile of flow rates entering the well under pumping conditions.

Profiles of flow rates recorded in each well while pumping are presented in Appendix A. Data were recorded at vertical increments of one foot. The exception was for MW 20 where increments of 0.5 feet were recorded throughout the five-foot screen.

As anticipated, a significant percentage of bypass flow was observed in the wire-wrapped screens. The percentage of bypass flow in the screened portion of the well was computed by comparing data recorded above the top of the screen with the measured pump flow rate above ground. For the wire wrapped screens, the calibration factor was about 2. No calibration was required for those wells with PVC slotted screens. Data shown in Appendix A have been adjusted to account for the bypass flow in those wells containing wire wrapped screens. Significant parameters and features of each well are included in each graph as notes to assist in interpretation. Questionable data points were omitted from the graphs.

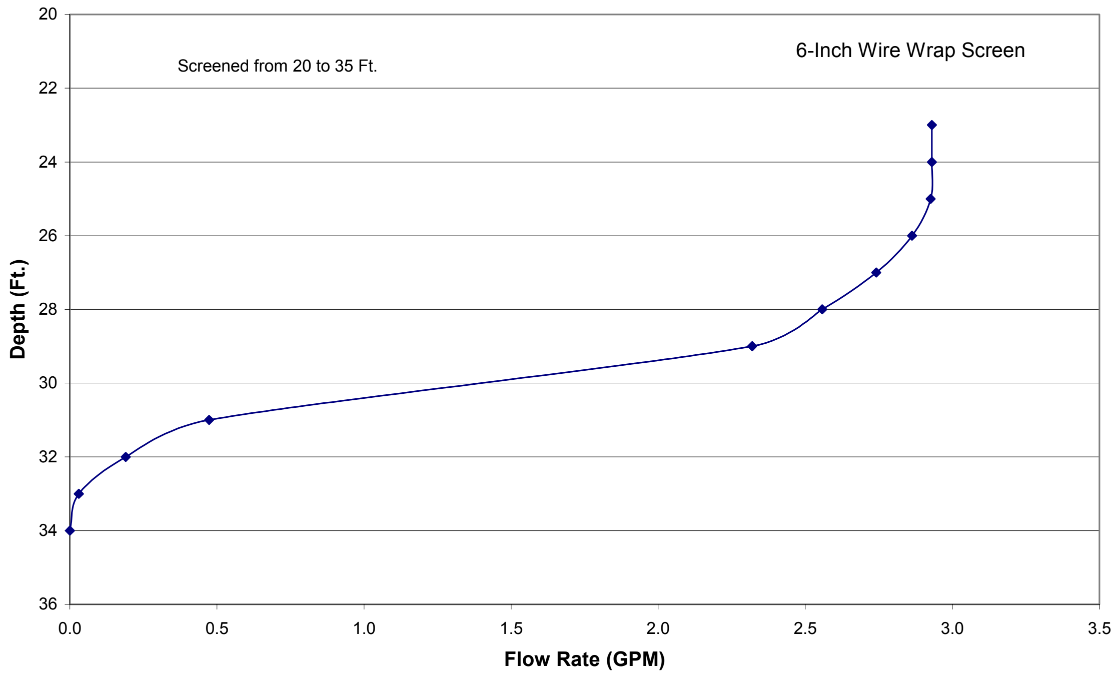
The profile of flow rate for each well was used to compute profiles of relative hydraulic conductivity by the procedure described in Waldrop and Pearson (2002). As requested by staff of PNNL, these data were normalized to show the percentage of the total hydraulic conductivity in each one-foot interval. Profiles for each well are presented in Appendix B. These data illustrate the geologic heterogeneity of the 10 wells tested with the EBF.

References

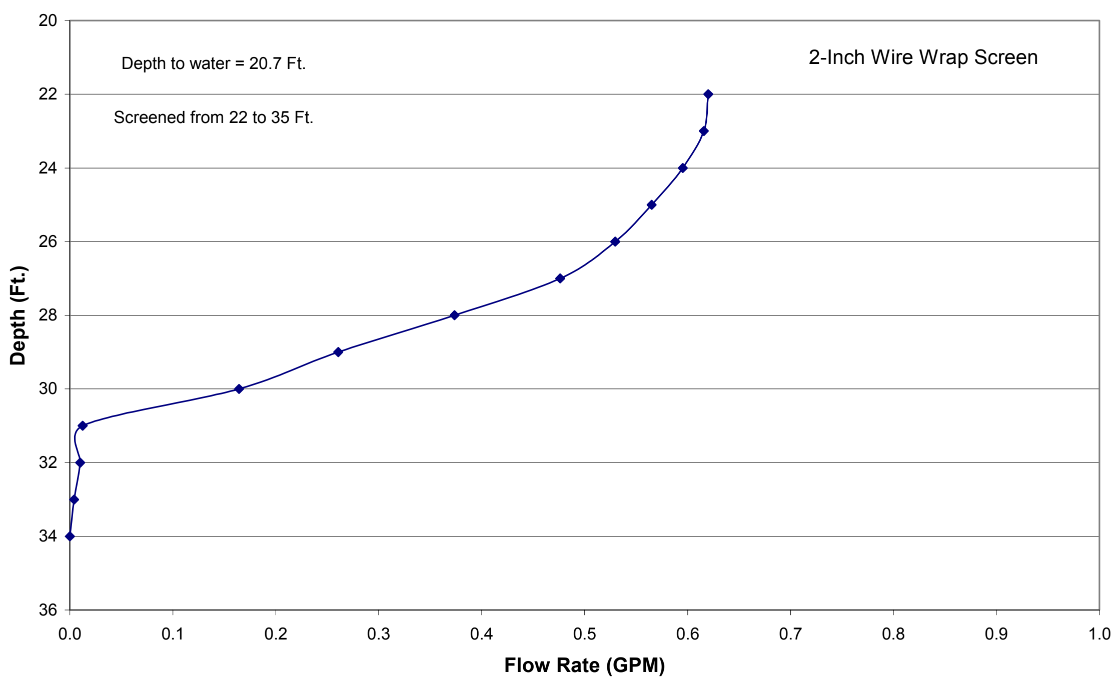
Molz, F.J., G.K. Boman, S.C. Young, and W.R. Waldrop, (1994), Borehole Flowmeters: Field Applications and Data Analysis, Journal of Hydrology, No. 163, pp. 347-371.

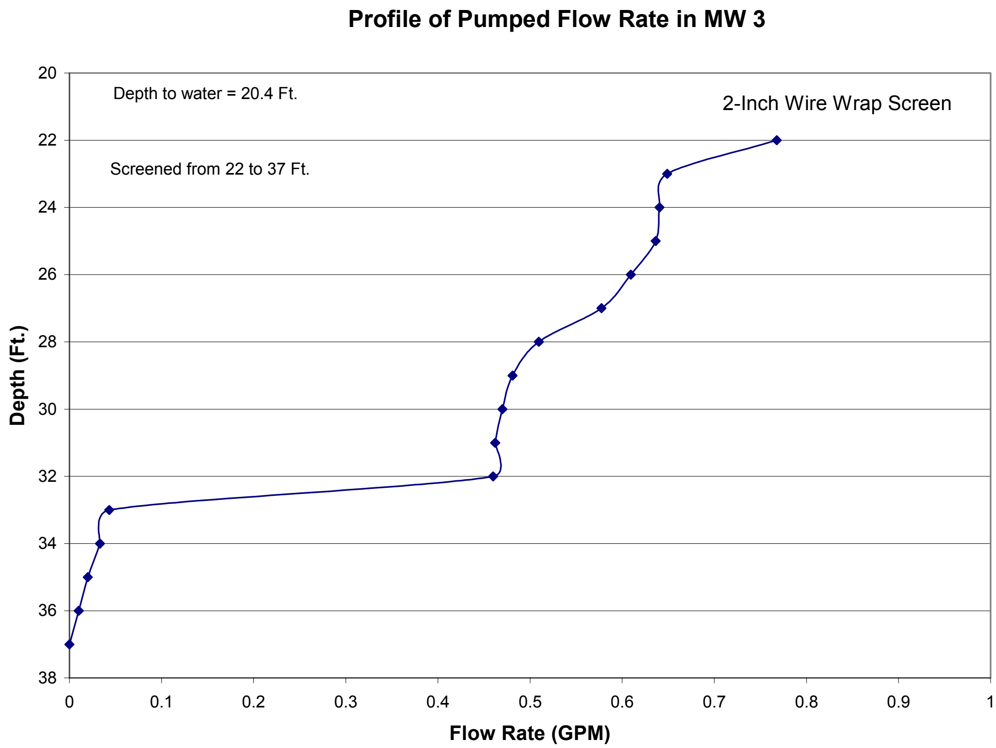
Waldrop, William R. and Hubert S. Pearson (2002), Results of Field Tests with the Electromagnetic Borehole Flowmeter at the 100-D Area In Situ Redox Manipulation Barrier Site, Pacific Northwest National Laboratory, Quantum Engineering Corp. Report QEC-T-146.

Profile of Pumped Flow Rate in Injection Well 1

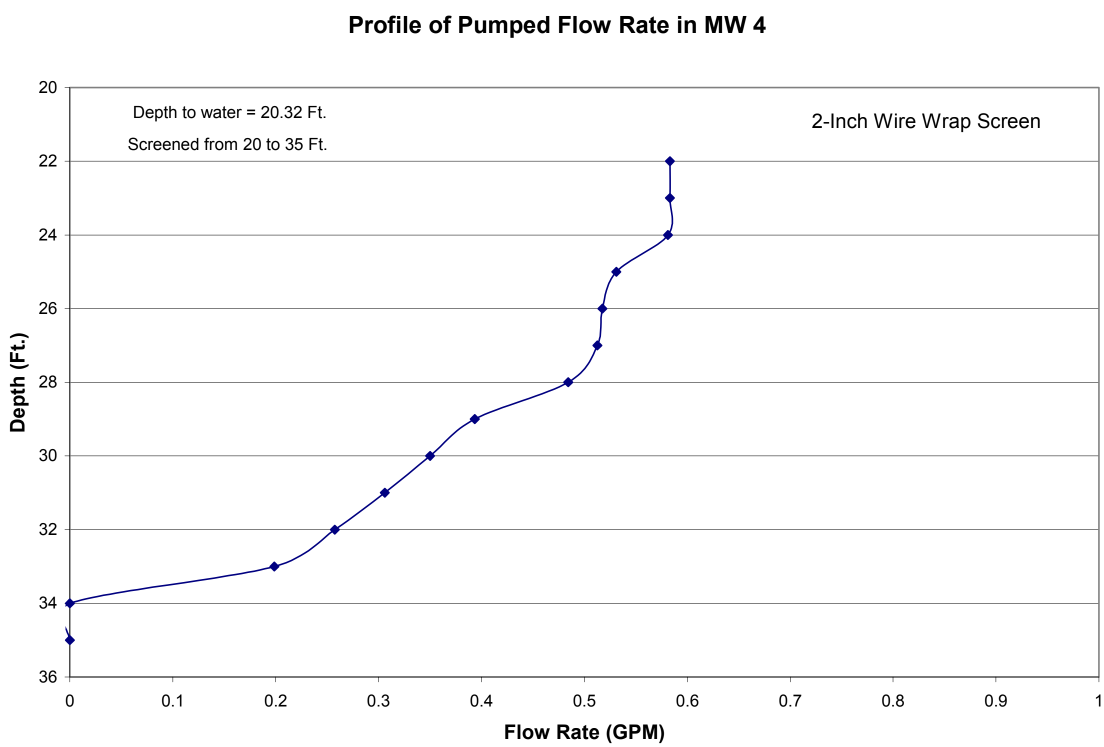


Profile of Pumped Flow Rate in MW 1

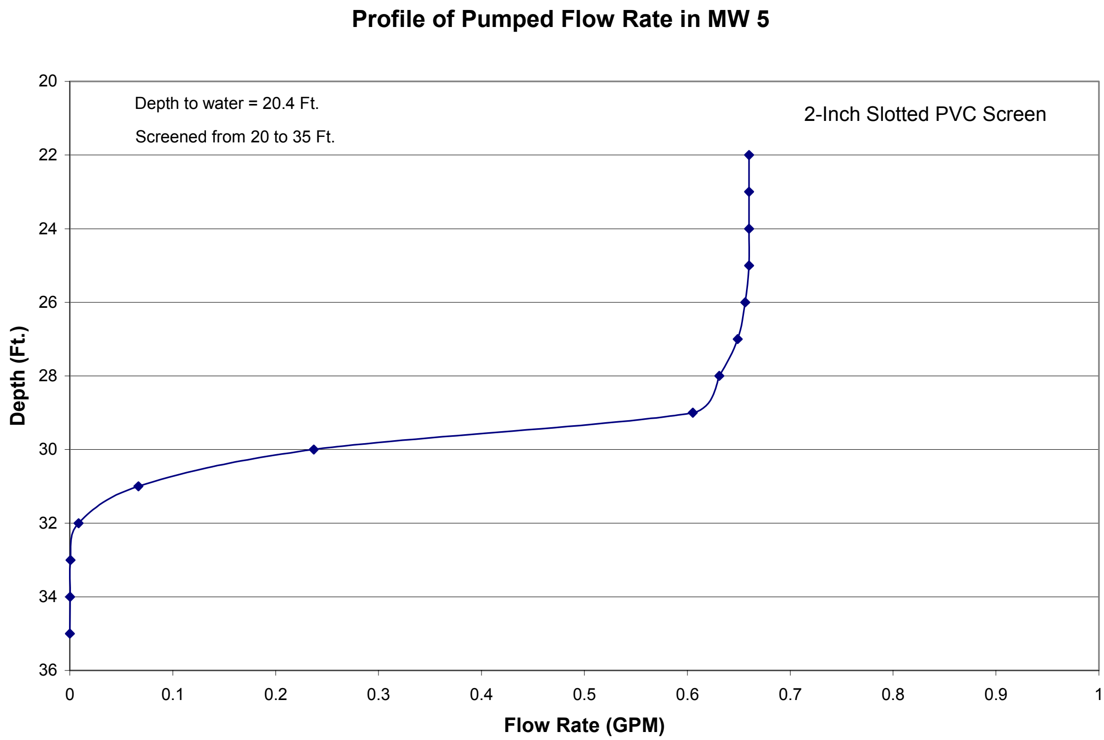


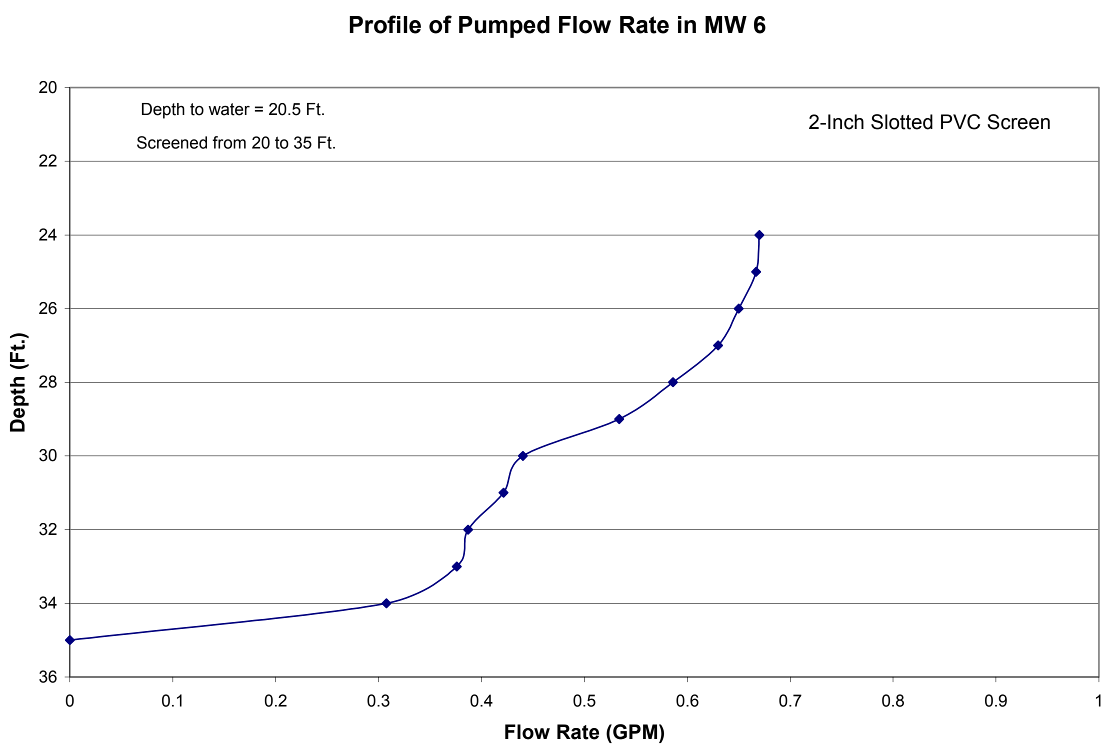


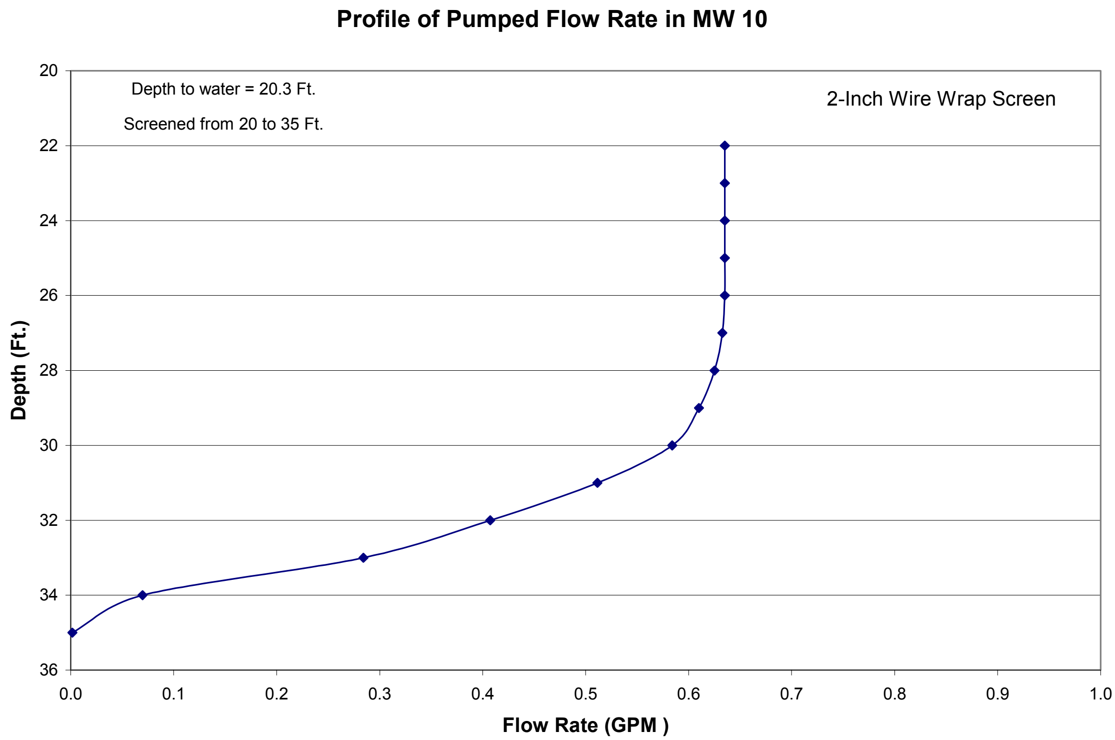
Profile of Pumped Flow Rate in MW 3
Depth to water = 20.4 Ft.
Screened from 22 to 37 Ft.
2-Inch Wire Wrap Screen
Depth (Ft.)
Flow Rate (GPM)

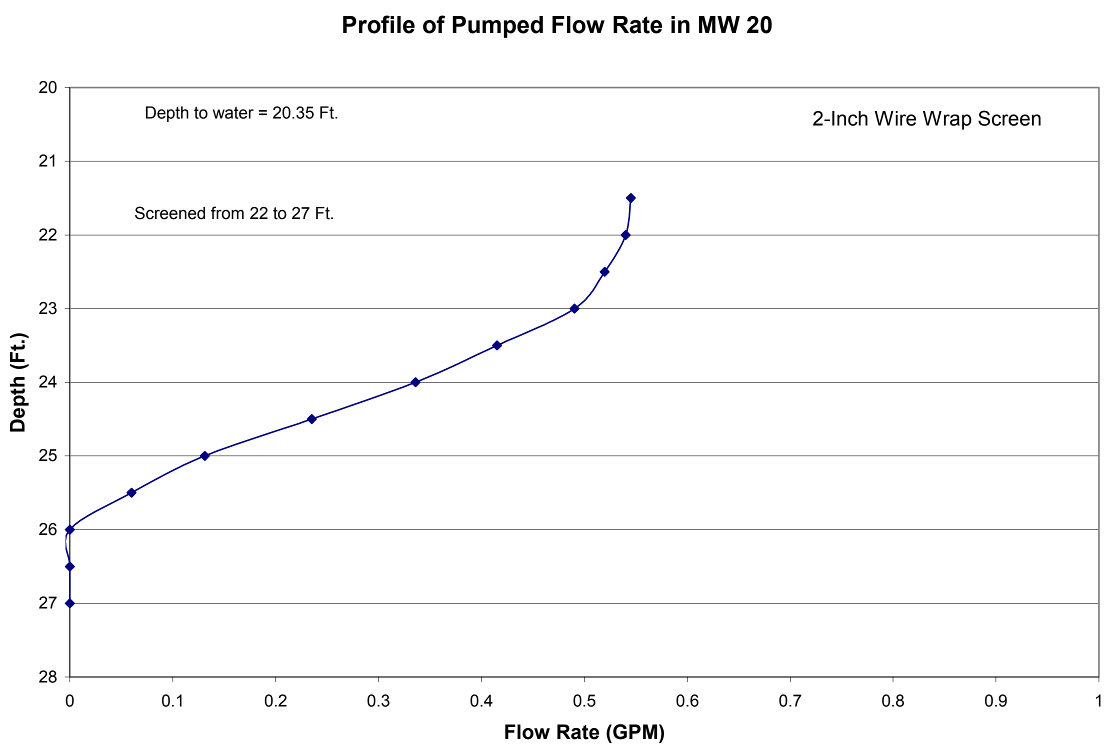


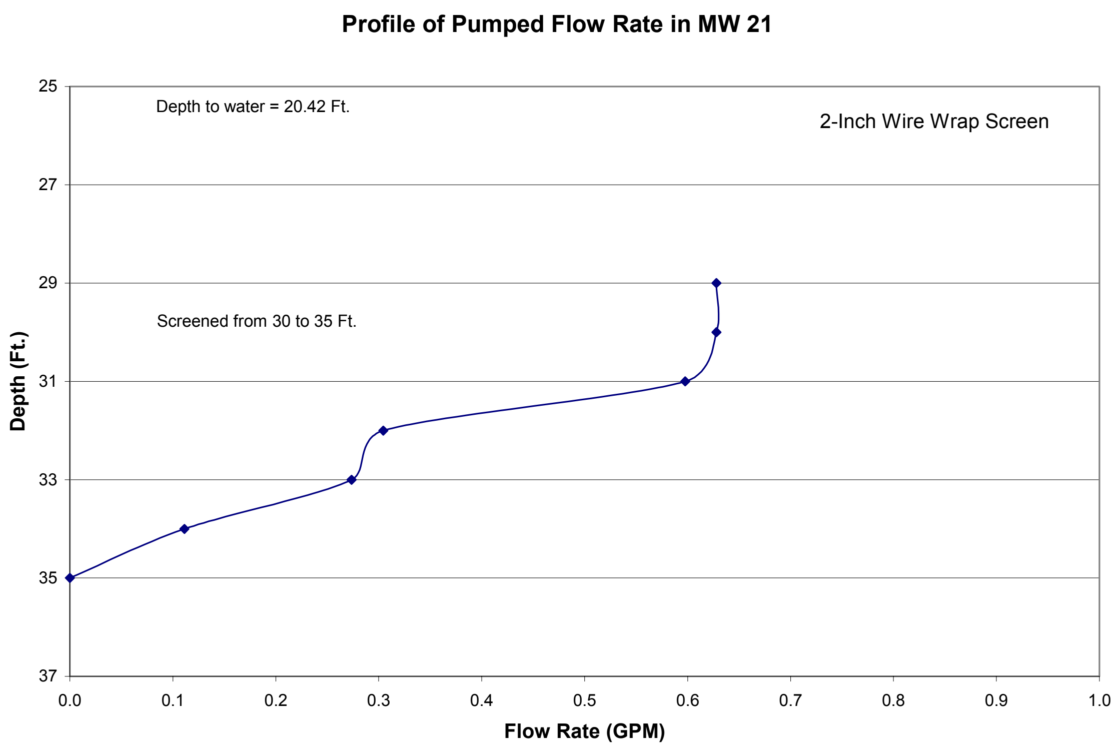
Profile of Pumped Flow Rate in MW 4
Depth to water = 20.32 Ft.
Screened from 20 to 35 Ft.
2-Inch Wire Wrap Screen
Depth (Ft.)
Flow Rate (GPM)


Profile of Pumped Flow Rate in MW 5
Depth to water = 20.4 Ft.
Screened from 20 to 35 Ft.
2-Inch Slotted PVC Screen
Depth (Ft.)
20
22
24
26
28
30
32
34
36
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Rate (GPM)

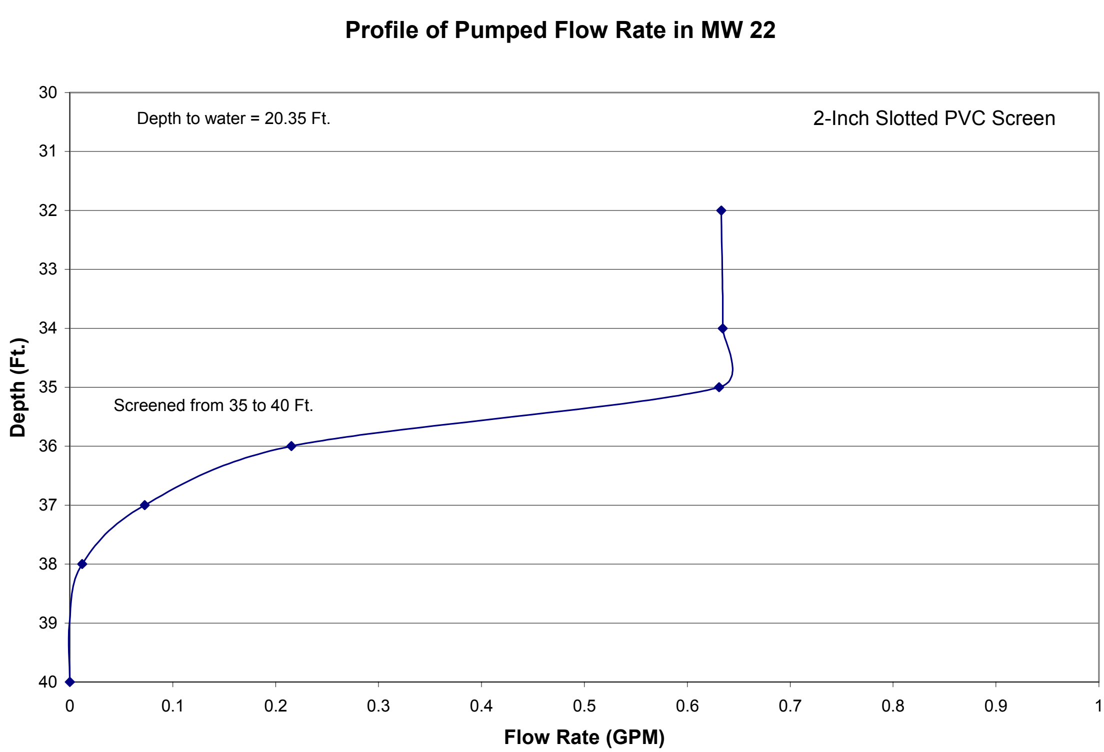

Profile of Pumped Flow Rate in MW 6
Depth to water = 20.5 Ft.
Screened from 20 to 35 Ft.
2-Inch Slotted PVC Screen
Depth (Ft.)
20
22
24
26
28
30
32
34
36
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Rate (GPM)


Profile of Pumped Flow Rate in MW 10
Depth to water = 20.3 Ft.
Screened from 20 to 35 Ft.
2-Inch Wire Wrap Screen
Depth (Ft.)
20
22
24
26
28
30
32
34
36
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Flow Rate (GPM)


Profile of Pumped Flow Rate in MW 20
Depth to water = 20.35 Ft.
Screened from 22 to 27 Ft.
2-Inch Wire Wrap Screen
Depth (Ft.)
20
21
22
23
24
25
26
27
28
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Rate (GPM)

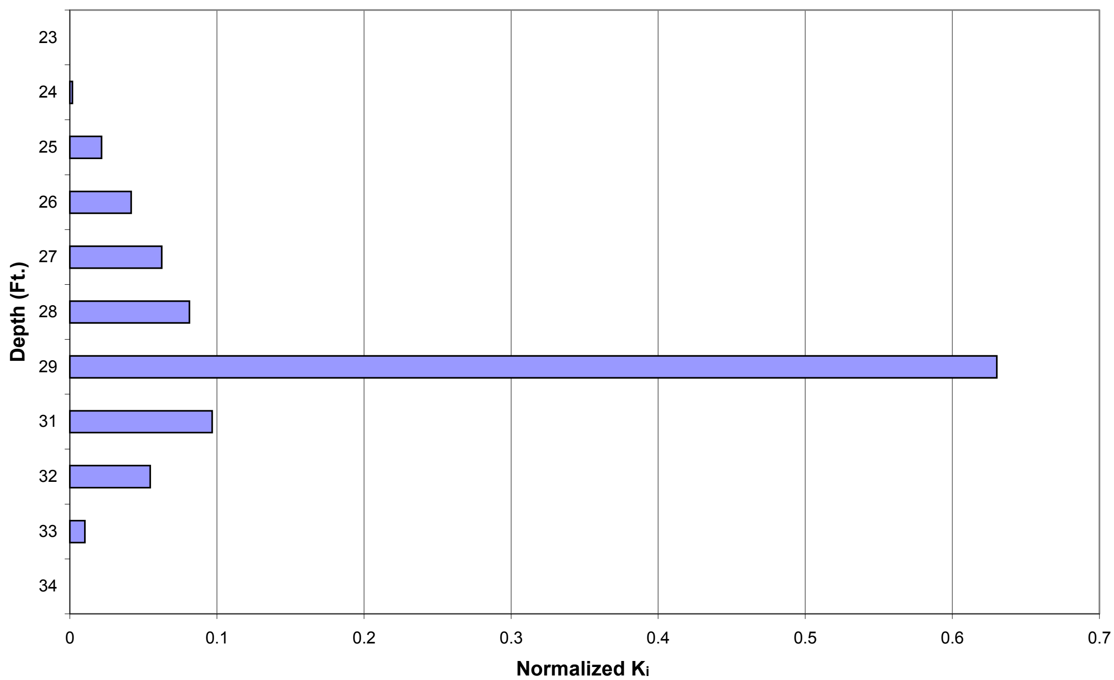


Profile of Pumped Flow Rate in MW 21
Depth to water = 20.42 Ft.
2-Inch Wire Wrap Screen
Screened from 30 to 35 Ft.
Depth (Ft.)
25
27
29
31
33
35
37
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Flow Rate (GPM)

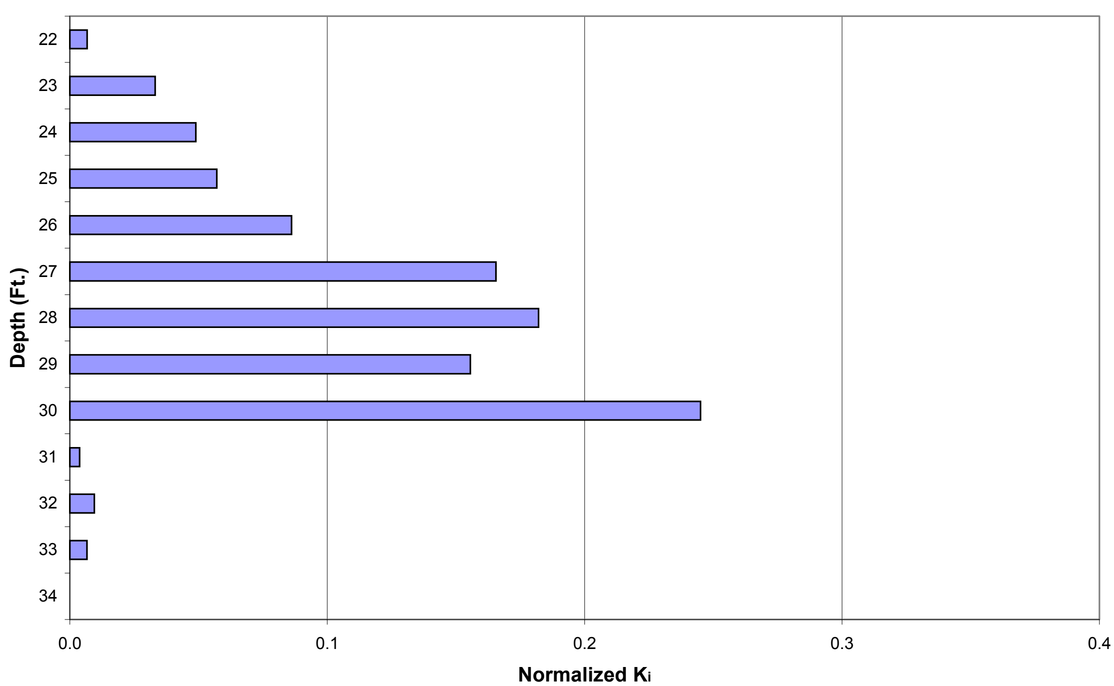


Profile of Pumped Flow Rate in MW 22
Depth to water = 20.35 Ft.
2-Inch Slotted PVC Screen
Screened from 35 to 40 Ft.
Depth (Ft.)
30
31
32
33
34
35
36
37
38
39
40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow Rate (GPM)

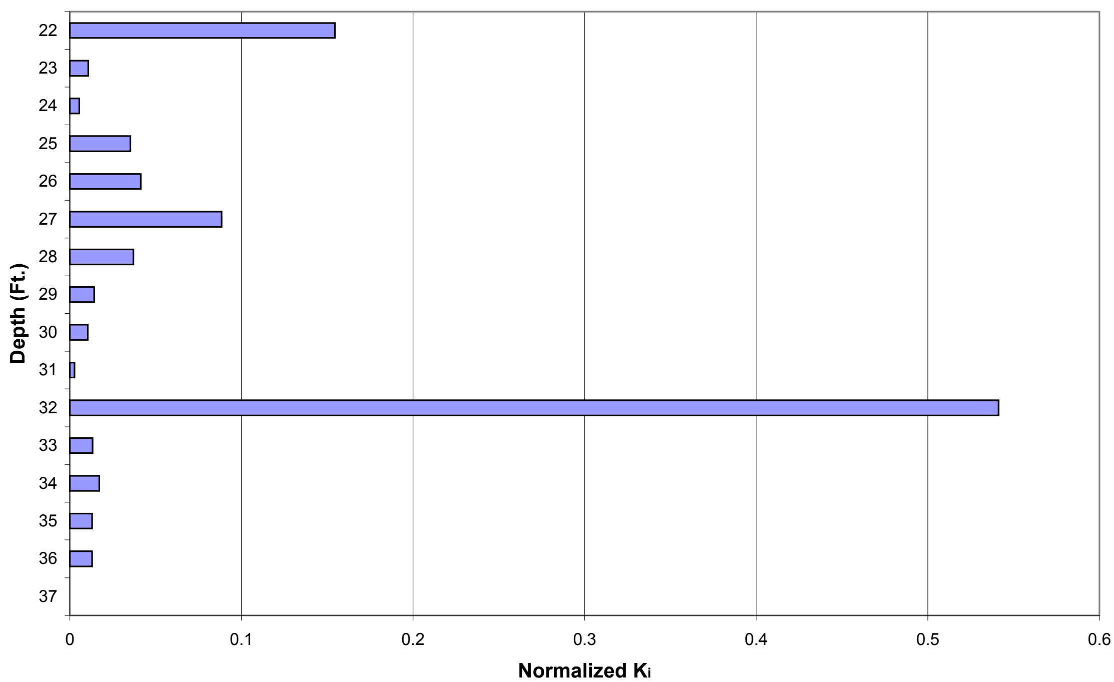
Normalized Profile of Hydraulic Conductivity for Injection Well 1



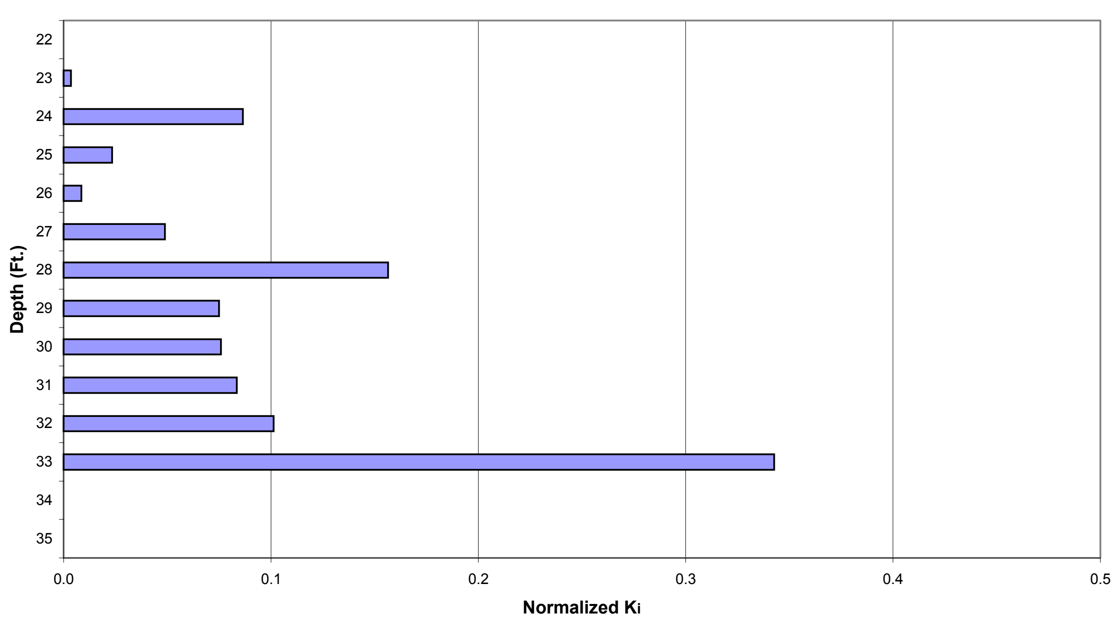
Normalized Profile of Hydraulic Conductivity for MW 1

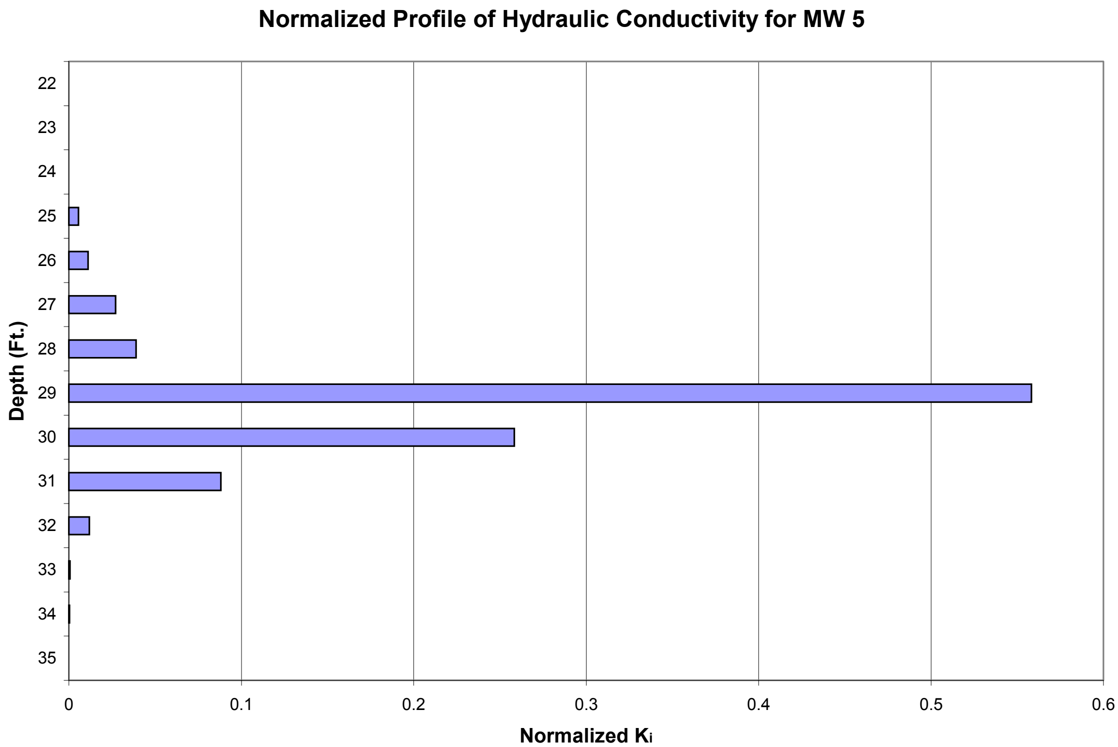


Normalized Profile of Hydraulic Conductivity for MW 3

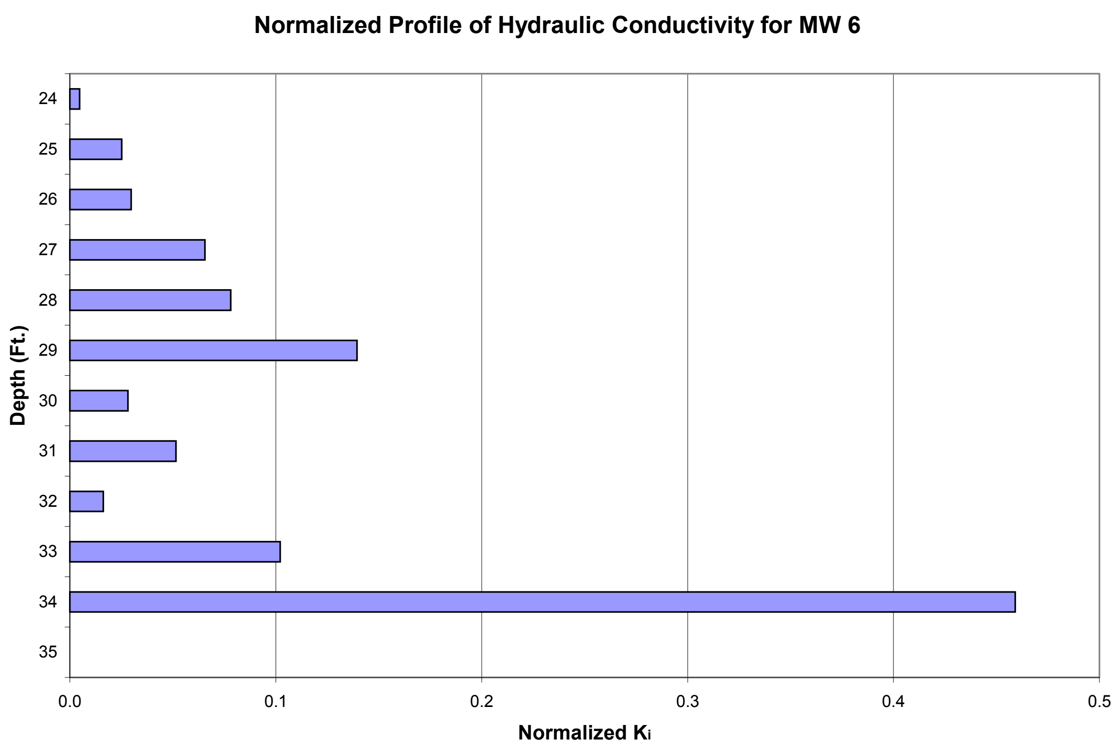


Normalized Profile of Hydraulic Conductivity for MW 4



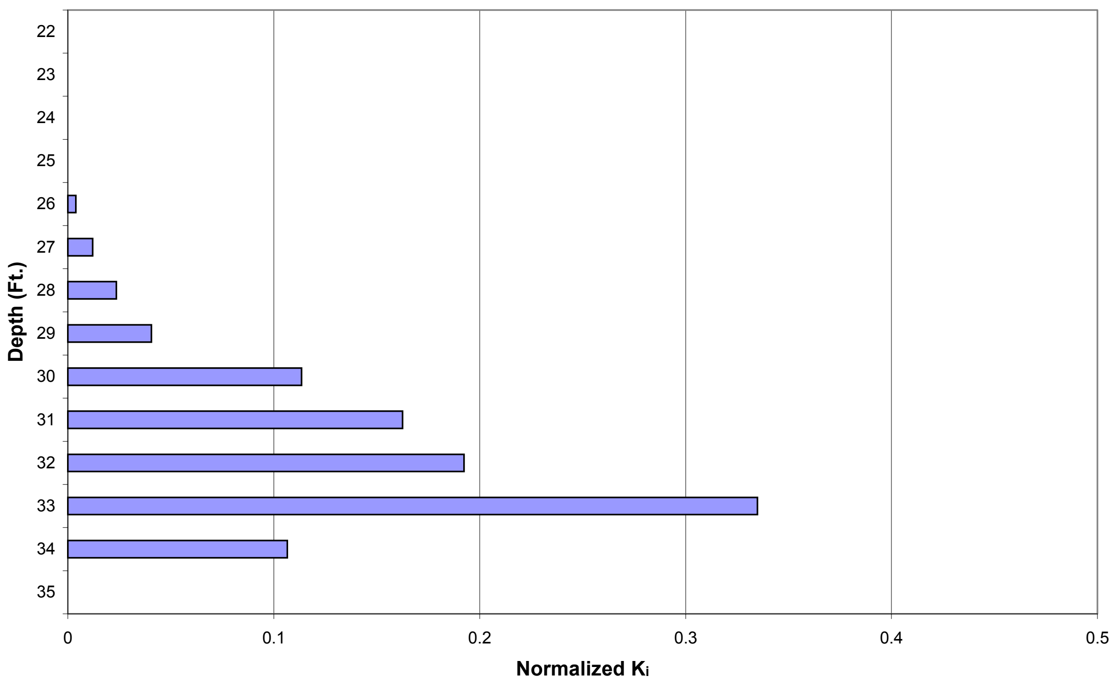


Normalized Profile of Hydraulic Conductivity for MW 5
Depth (Ft.)
22
23
24
25
26
27
28
29
30
31
32
33
34
35
0
0.1
0.2
0.3
0.4
0.5
0.6
Normalized Ki

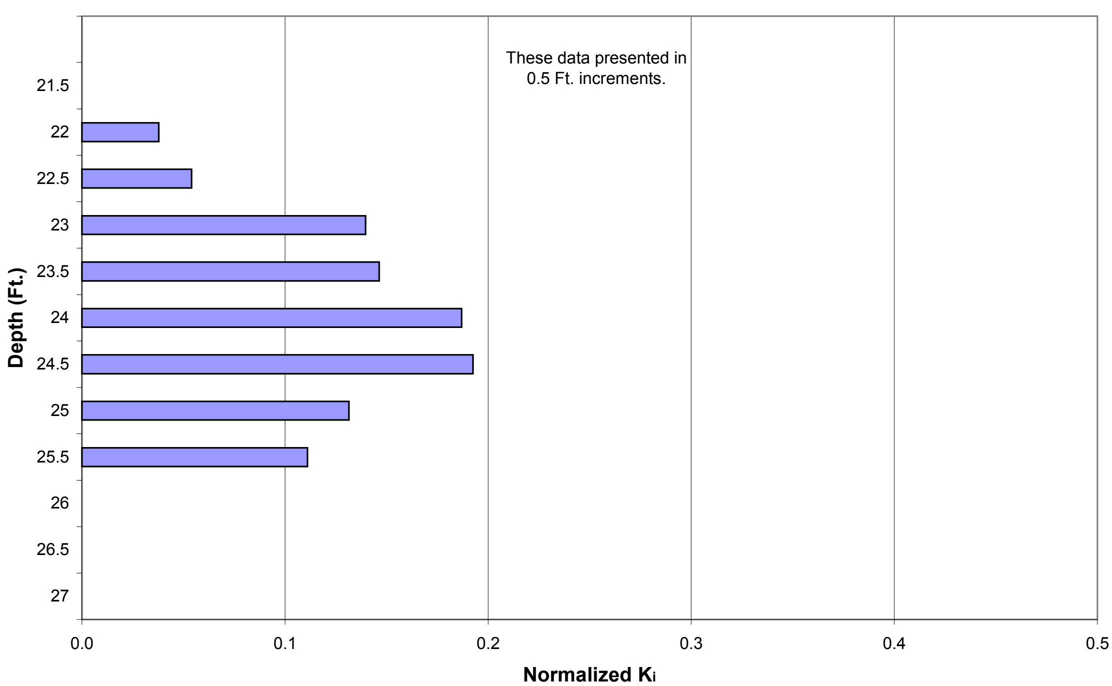


Normalized Profile of Hydraulic Conductivity for MW 6
Depth (Ft.)
24
25
26
27
28
29
30
31
32
33
34
35
0.0
0.1
0.2
0.3
0.4
0.5
Normalized Ki

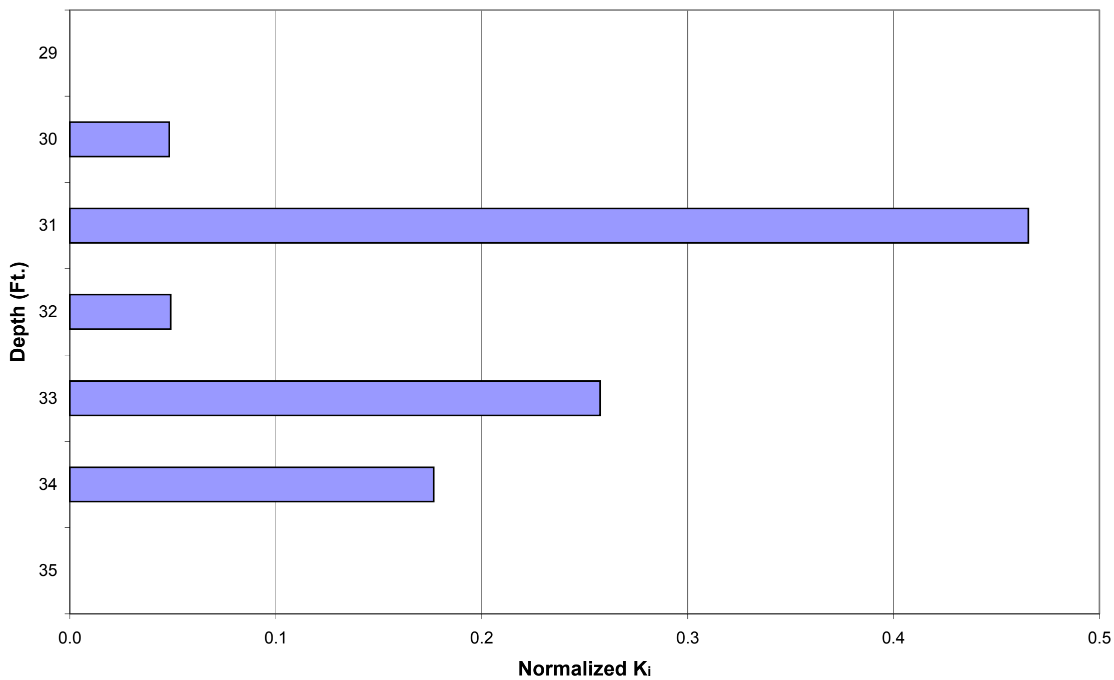
Normalized Profile of Hydraulic Conductivity for MW 10



Normalized Profile of Hydraulic Conductivity for MW 20



Normalized Profile of Hydraulic Conductivity for MW 21



Normalized Profile of Hydraulic Conductivity for MW 22